AD-A126 764 EFFECTS OF MOUNTAIN RANGES ON MESOSCALE SYSTEMS DEVELOPMENT(U) COLORADO STATE UNIV FORT COLLINS DEPT OF ATMOSPHERIC SCIENCE E R REITER ET AL. OCT 82 1/1

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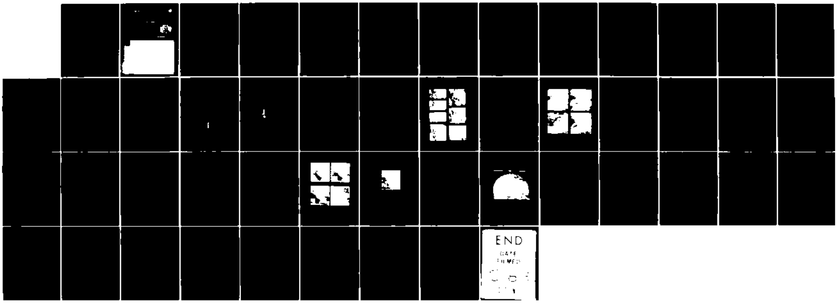

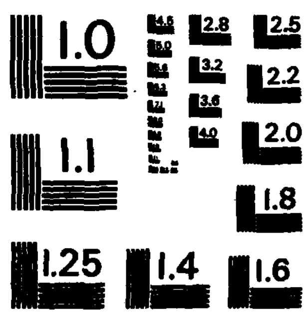

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFOSR-TR- 83 - 0220
2. GOVT ACCESSION NO.: A126 764
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Effects of Mountain Ranges on Mesoscale Systems Development
5. TYPE OF REPORT & PERIOD COVERED: Interim Report
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Elmar Reiter, John Sheaffer, Majorie Klitch, Ray McAnelly and Donna Tucker
8. CONTRACT OR GRANT NUMBER(s): AFOSR 82-0162
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado 80523
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F, 2303/A1
11. CONTROLLING OFFICE NAME AND ADDRESS: AFOSR/NC, Bldg 410, Bolling AFB, DC 20332
12. REPORT DATE: October 1982
13. NUMBER OF PAGES: 46
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited
17. DISTRIBUTION ST. [illegible] ENT (of [illegible] abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY [illegible] TES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Mesoscale Convective Complexes
MCC
Mesoscale Dynamics
Mesoscale Modeling
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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20. Abstract (Cont)

In this report progress during the first six months of an effort to examine the role of elevated terrain in the initiation and development of mesoscale convective weather systems over the midwestern U.S. and eastern China is discussed. Major areas of activity presented include data acquisition, the development of a climatology of convective system occurrence, the identification of areas of frequent initial convective activity over the eastern slopes of the Rocky Mountains, and the presentation of several preliminary case studies. Also discussed is the initial evaluation of numerical modeling efforts to be made for case study analyses.

EFFECTS OF MOUNTAIN RANGES ON MESOSCALE SYSTEMS DEVELOPMENT

Interim Progress Report to
U.S. Air Force Office of Sponsored Research
Grant No. AFOSR 82-0162

Work Conducted Between 15 April 1982 and
15 October 1982

by

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October 1982

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EFFECTS OF MOUNTAIN RANGES ON MESOSCALE SYSTEM DEVELOPMENT

1. Introduction

1.1 Proposed Research Tasks

This progress report briefly describes our work conducted between 15 April, 1982 and 15 October 1982 -- the first 6 months of a 36-month grant period -- under U.S. Air Force Office of Sponsored Research Grant No. AFOSR 92-0162. According to our original proposal, the following research tasks have to be carried out:

(1) Assembly of a data bank for spring and summer of surface and upper air data of the region of the North American continent between 90°W and 115°W and between 20°N and 50°N, and of regions of the Tibetan Plateau and its surroundings for as many years as feasible. Collection of satellite (IR and visible channel) data for appropriate time periods of concern will proceed at the same time.

(2) Synoptic studies of severe weather and heavy, extensive convective precipitation events.

(3) Establishment of a synoptic climatology of the atmospheric structure associated with the initiation and development of the weather events including heavy, extensive convective rainfall over the two different regions.

(4) Development of numerical models to simulate the initiation and development of mesoscale convective complexes.

1.2 Publications

During the past grant period the following papers have been submitted for publication:

Ding, Y.-H. and E.R. Reiter, 1982: A Relationship Between Planetary Waves and Persistent Rain- and Thunderstorms in China. Arch. Met. Geoph. Bioklim. (in press).

Reiter, Elmar R., 1982: Typical Low-Tropospheric Pressure Distributions Over and Around the Plateau of Tibet. Arch. Met. Geoph. Bioklim. (in press).

The "Typical low-tropospheric pressure distributions over and around the Plateau of Tibet" also were discussed by the P.I. at a Workshop on Mountain Meteorology which was held in Beijing, P.R.C., May 17, to June 8, 1982.

2. Work Progress

2.1 Introduction

This report summarizes progress during the first six months of work examining the role of elevated terrain areas in the initiation and development of mesoscale convective weather systems over the midwestern United States and eastern China. Maddox (1980) has described a particular class of these storms which he calls Mesoscale Convective Complexes (MCCs). For the sake of convenience we will use this MCC abbreviation although we do not strictly confine our studies to systems that meet all of Maddox's criteria. Points of major emphasis include data acquisition activities in support of our studies, the development of a climatology for the occurrence of mesoscale convective systems, the identification of areas of frequent initial convection over the eastern slopes of the Rocky Mountains, and some preliminary MCC case studies. In addition, we are testing several numerical modelling procedures for examining the details of the initiation and development of mesoscale convective systems, of the surface energy exchanges and conversions over the plateau areas and of the horizontal transport of atmospheric moisture.

2.2. Data Base Development

A large amount of meteorological data has already been collected. They are described below in the discussions of the specific research tasks for which they were acquired.

To study the mechanisms leading to the initiation and development of MCCs, we need to define perturbations relative to the climatological means of meteorological parameters. We are in the process of developing monthly mean patterns of the diurnal variation of several key meteorological parameters at the surface, in the boundary layer and also in the free atmosphere over the Rocky Mountains and the Tibetan Plateau. These parameters include wind speed and direction, station pressure, cloud cover, air temperature and dew point. The bulk of the meteorological observations are being obtained from the data archives of the National Center for Atmospheric Research (NCAR) and from the National Climatic Center (NCC).

The primary NCAR data set available for our study is the NMC-ADP data archive (Jenne, 1975). This worldwide data set includes both surface and upper air observations, synoptically ordered as available, for 0, 6, 12 and 1800 Z. Five years of July surface observations for an area spanning the mountain and plateau area of the western United States were obtained from this data set. These data were examined for completeness of record and for the density of station coverage. A small amount of similar data were also obtained for the Tibetan Plateau and for adjacent regions of India, China, and Southeast Asia. Of the 72 U.S. stations that reported during the five July periods, only 26 reported more than 90 percent of the time. Based on this evaluation we have decided instead to acquire surface data for selected U.S. stations

from the TDF-14 series (Jenne, 1975) at NCC. These data tapes, though expensive, provide at least equivalent station coverage with either 8 or 24 observations per day, for essentially the same total cost. Moreover, all Colorado tapes of this series are already in our CSU data archives.

The NCAR data for the Tibetan area contain observations for nearly 400 stations for the one day of data examined. Sixty-eight of these stations are situated on the plateau at elevations above 9000 feet. These data appear to be the best readily available observations for this area and will be the primary climatological data base for our Asian surface climatologies.

A collection of supplemental Chinese and Tibetan surface observations has recently been delivered to us by Professor Maocang Tang of Lanzhou Institute of Plateau Atmospheric Physics who will be working with our research group during the next six months. Notable in these data are daily soil temperatures (surface and nine levels to 3.2 meters) and surface evaporation measurements.

A fairly complete collection of upper air data, including rawinsondes, pibal and aircraft observations is available at NCAR. We have also recently acquired a set of rawinsonde data (published hard copy, Central Meteorological Bureau, Beijing, 1979) for more than 120 Chinese and Tibetan stations for all of 1979.

Because the digital data described above are expensive to acquire, we have temporarily delayed the acquisition of the bulk of these data pending the completion of several preliminary studies that will define the specific area in the U.S. and Asia to be examined in detail.

2.3. Climatology of Mesoscale Convective Systems

The identification of a large number of mesoscale convective weather systems over both the U.S. and eastern Asia is our highest immediate priority. This collection of storm system cases is needed to initially define (1) the best areas for which surface and upper air climatological data should be developed, (2) the range of synoptic conditions under which these systems appear, (3) the comparative nature of these storms in the U.S. and China, and (4) a list of representative individual storm systems to be studied in depth. We are constructing our MCC climatology from satellite imagery, from the recent literature and through communication with Chinese scientists involved in similar research.

Maddox (1980, 1981) presented a climatology of satellite defined MCCs over the U.S. for a two-summer period. It consisted of tracks, times and locations of initial convection, maturation, maximum size and decay, the maximum cloud extent and associated severe weather reports. Our climatology of storms in the U.S. is somewhat more extensive. We are including some systems which do not meet Maddox's criteria and we are further classifying MCCs by the synoptic regime associated with each. By stratifying convective systems by synoptic regime a clearer relation to synoptic weather types may be identified.

Specific elements included in our U.S. climatology are:

(1) [illegible] types of

[illegible]

(3) Statistics on the time of first convection, meso-α scale initiation, maximum size, most intense convection, meso-α scale decay and tracks.

(4) Synoptic types and other weather elements associated with each class of system including the occurrence of the upper-level divergence, low-level convergence, moisture gradients and convergence, and the low-level jet.

The data base being used for our U.S. MCC climatology includes (in addition to routinely available weather maps and synoptic data) a nearly complete set of North American enhanced infrared laserfax images from the Geostationary Orbiting Environment Satellite (GOES-East) for June, July and August, 1981. The enhancement scheme of the imagery is the "MB" enhancement which Maddox (1980) used in the definition of mesoscale convective complexes. Also available in our CSU archives is an extensive set of hemispheric GOES-East and GOES-West visible and infrared hard copy imagery dating from the present back through 1977. These data will allow an extensive satellite climatology of mesoscale systems to be developed for the area over and downwind of the rockies.

Our MCC climatology for China includes most of the same items as our U.S. climatology but is somewhat limited at present by both the quantity and quality of data available to us. We have already examined visible and infrared imagery from the Japanese Geostationary Satellite (GMS) which have been obtained for the 1979 MCC season only. This microfilm imagery has been obtained on loan from the University of Wisconsin. We also have a limited amount of imagery from the GOES-1 satellite which was temporarily positioned over the Indian Ocean during this same (1979) time period in conjunction with the summer MONEX

experiment. An inexpensive source of large amounts of additional Japanese imagery for other years has not yet been identified.

Synoptic maps and data tabulations for the surface, 850, 700 and 500 mb surfaces have been obtained from the Japanese Meteorological Agency. Similar, but more detailed analyses to 200 mb for May and June 1979 are presented in the "Quick Look Summer MONEX Atlas", Parts I and II (Krishnamurti et al., 1979).

Preliminary analyses of the Japanese satellite data for June and July 1979 suggest that, in general, the Asian MCC systems tend to be smaller, less frequent and less persistent than the systems observed in North America. A northward shift of about 5° latitude of the mean track of these systems from June to July was also apparent. More exact analyses of these Asian MCC systems in terms of Maddox's (1980) criteria is presently complicated by the lack of precise calibration information for cloud top temperatures in the Japanese infrared imagery.

Shen Rujin, a Chinese scientist at the Academia Sinica in Beijing, has recently sent us a list of cases wherein upper level "vortices" were observed to form over the Tibetan Plateau and farther to the east during the spring and summer seasons. These vortices were diagnosed from 500 mb data for the period from May, 1978 through August, 1981. For the spring and summer of 1979 there appears to be only partial concurrence between Shen's list of vortices and the appearance of large cloud shields east of the plateau. Since Shen's list gives only approximate dates and no specific locations for these vortices, we are not sure that we are discussing the same phenomena. We intend to reconcile these questions and learn a great deal more about plateau induced atmospheric circulations when Professor Shen joins us this October for an extended visit.

2.4. Case Studies of Mesoscale Convective Systems (U.S.).

Maddox (1980, 1981) has defined the midlatitude MCC as a unique class of convection, organized on the meso-α scale (250-2500 km, > 6 hours; see Orlanski, 1975), which is often accompanied by severe weather, and which accounts for much of the convective season precipitation over a large portion of the central U.S. His satellite-based definition of an MCC requires a meso-α scale, near circular shape and a long-lived, cold cloud shield. This definition isolates the large end of what satellite data suggest is a continuous spectrum of dynamically similar convective systems extending down to the meso-β scale (< 250 km, < 6 hours). There also appears to be a continuous spectrum of mesoscale convective system types, ranging from the classical squall line in a strongly forced baroclinic environment on one hand, to the "classical" MCC in a relatively quiescent environment with more subtle forcing on the other hand. While we are not restricting our study to the MCC end of the convective spectrum, the background work on MCC's by Maddox makes this system the appropriate place to concentrate our initial case study efforts.

In addition to learning more about the general life cycle of the MCC in these studies (including its larger-scale environmental processes, its substructure, and the scale interactions involved in its evolution), we emphasize the upstream role of the Rocky Mountains in their generation. Ongoing research at CSU has already examined several aspects of mesoscale weather systems. Hence, some of the results shown in this section were supported in part by several other research grants (see Acknowledgments) but are included to illustrate the approach we are taking in the analysis of MCCs.

Special data being employed in these case studies include a NMC grid point data set for July and August, 1977 for the region 0° to 60°N and 40° to 160°W at 2½° grid-point intervals, and at 10 mandatory pressure levels from 1000 to 100 mb. These data include heights, temperatures, mixing ratios, and u and v wind components. These data are derived from the pre-1978 NMC operational Hough (Jenne, 1975) spectral analysis, which solves for 7 vertical wave numbers and 24 latitudinal and longitudinal wave numbers. The derived wind fields are nondivergent so certain dynamical applications of these data will not be possible. The restriction to mandatory levels also limits resolution for the identification of certain significant features, such as the low-level jet. Nevertheless, the application of these data in studying the large-scale processes attendant to mesoscale convective cases should prove interesting. A similar but much larger gridded data set, the FGGE-Level III global analysis for all of 1979, is also available on the premises.

For a trajectory model (described later) we have used the NMC grid point data to create an isentropic-level data set interpolated onto 5°K-interval isentropic levels. These data consist of pressure, mixing ratio, the Montgomery stream function, u and v wind components, and the longitudinal and latitudinal gradients of the stream function.

Other special data in hand include sounding and mesonet observations from the SPACE/HIPLEX study of 1977, the Montana HIPLEX program (several summers since 1976), the Montana COPE study (1981) and the ongoing PROFS program along the eastern slope of the Colorado Rockies.

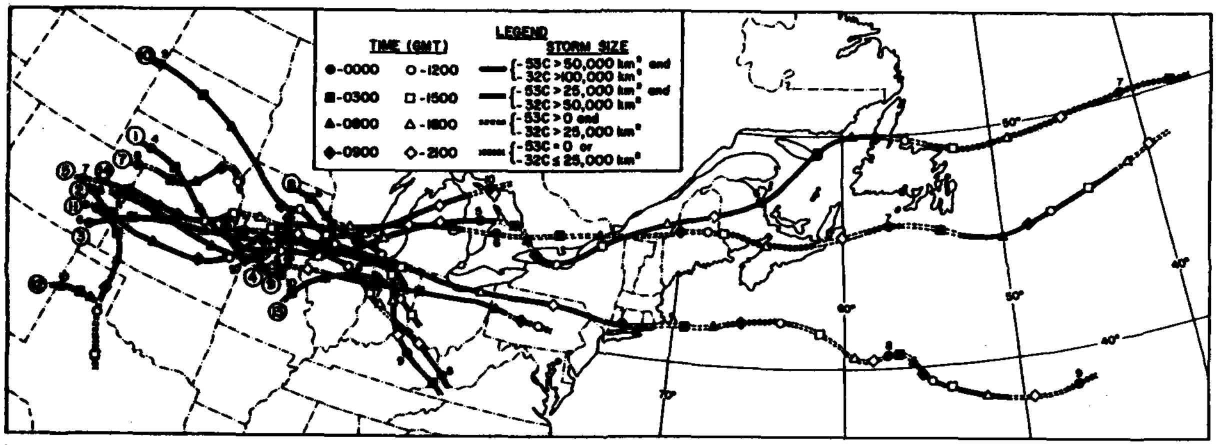
(a) MCC Episode of 3-10 August 1977

Satellite data reveal that MCCs tend to occur on successive days when a favorable quasi-stationary synoptic regime sets up. We have

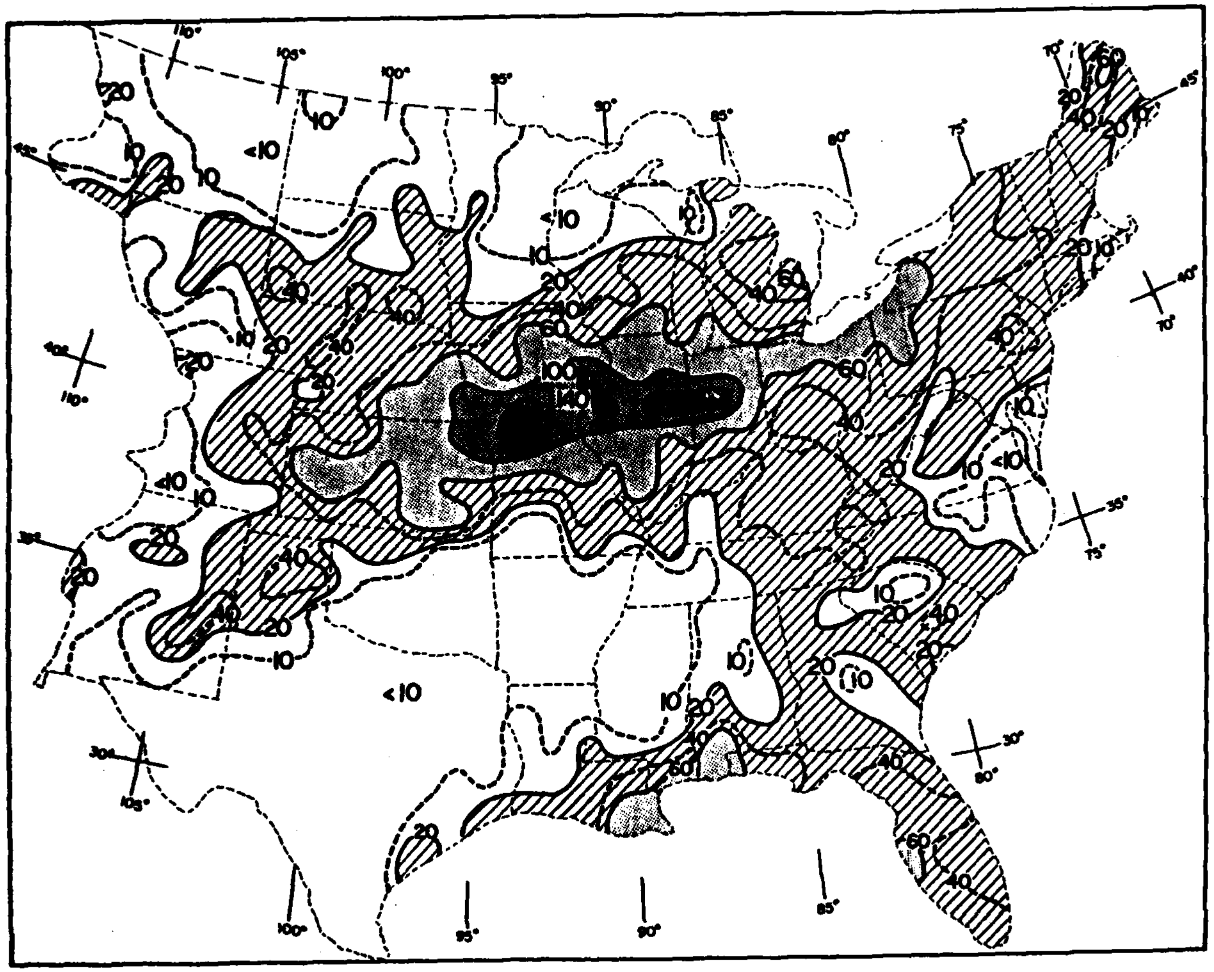
studied one such episode that occurred from 3-10 August 1977. During this time one or more MCCs formed daily, both on the High Plains and farther east, and dominated the weather over most of the central U.S. Figure 1 shows the trajectories of satellite-determined center points for the 14 systems identified during this period. The darkened tracks depict where and when the systems were mature by Maddox's (1980) criteria. Two rather distinct genesis centers are noted: one on the western High Plains of Colorado (designated as "western systems") and the other over the lower terrain of Iowa and Missouri ("eastern systems"). The tracks of these MCCs tended to follow the quasi-stationary surface front extending from the Oklahoma-Nebraska region to the Great Lakes and New England. Some of the systems persisted as identifiable regions of loosely organized convection (for up to three days) which occasionally reintensified into mature complexes.

The eight-day precipitation map for the episode (Fig. 2, analyzed for average values within each 1° latitude/longitude block) shows the dominance of the MCC activity on the central and eastern U.S. precipitation. Note that the heaviest precipitation band coincides with the general MCC track in Fig. 1.

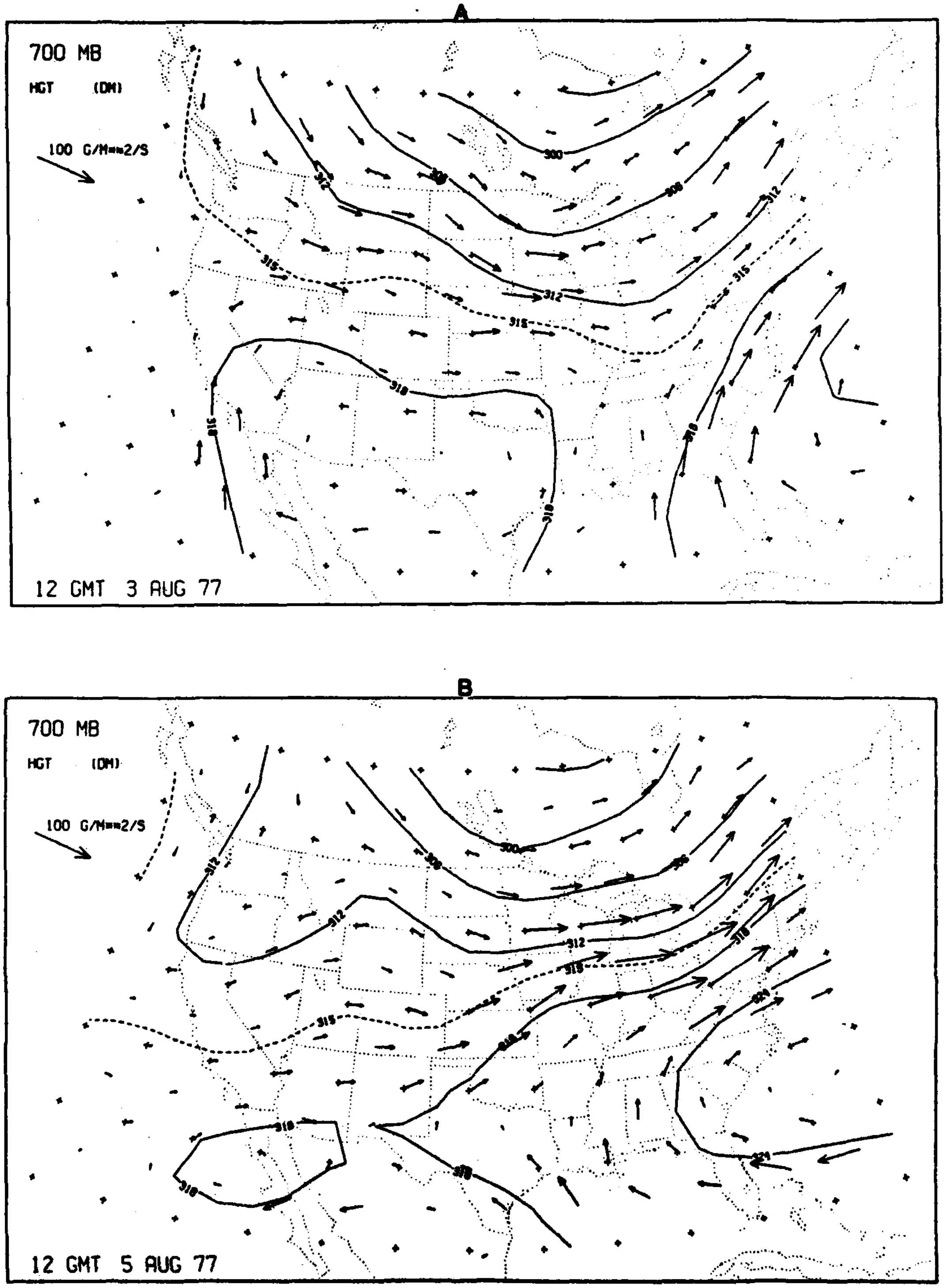
The most significant synoptic changes leading into the quasi-stationary pattern for this MCC episode were (1) a weakening of the southwestern U.S. subtropical ridge, (2) a corresponding cooling and troughing over the west coast and (3) westward building of the Atlantic subtropical ridge into the southeastern U.S. This transition, depicted in the 700 mb height and moisture flux vector fields at 1200 GMT, 3 August and 1200 GMT, 5 August are shown in Fig. 3. Similar pressure-pattern characteristics will be described in Chapter 2.6. This reordering of the synoptic configuration allowed a southerly stream of lower



1. Tracks of the centroids of the 14 MCCs which developed during the episode of 3-10 August 1977. The circled numbers represent the sequence of occurrence of the systems (McAnelly and Cotton, 1981).



2. Total August 3-10 episode precipitation distribution (millimeters) based on averaged station totals for one-degree grid squares. The number of stations per block ranged from 5 to 25, with 10 to 15 being most common (Wetzel et al., 1982).



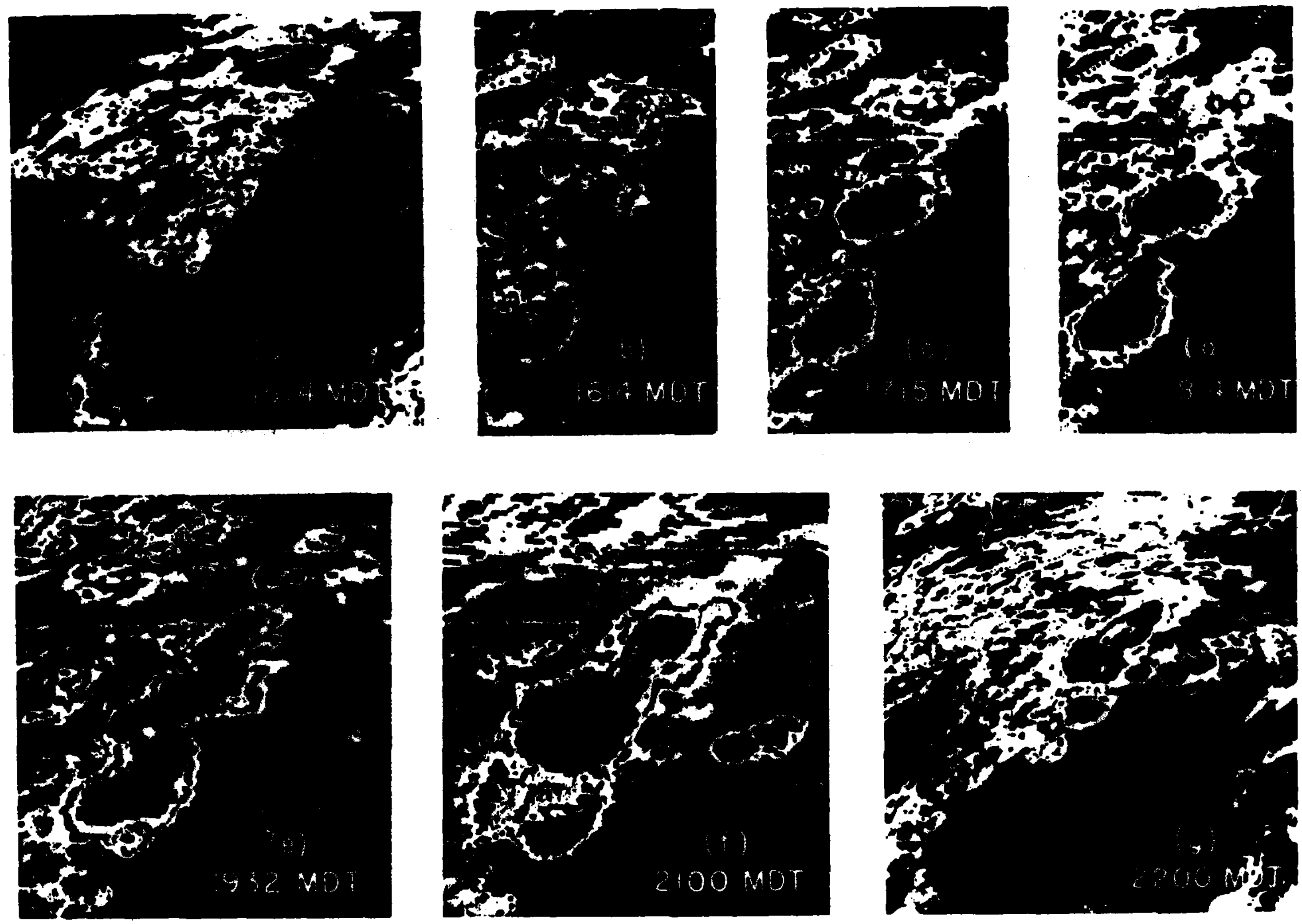
3. Height analysis (decameters) and moisture flux vectors (scaled to key in upper left) at 700 mb for (a) 1200 GMT, 2 August and (b) 1200 GMT, 5 August 1977, using NMC grid-point data.

tropospheric moisture from the Gulf of Mexico to feed the U.S. interior, while a west-southwesterly stream of Pacific moisture penetrated inland to the Colorado Rockies. The latter feature is important for the generation of the western MCC systems wherein the initial deep convection originates over the mountains. The former feature is crucial to the maintenance of the systems as they track eastward.

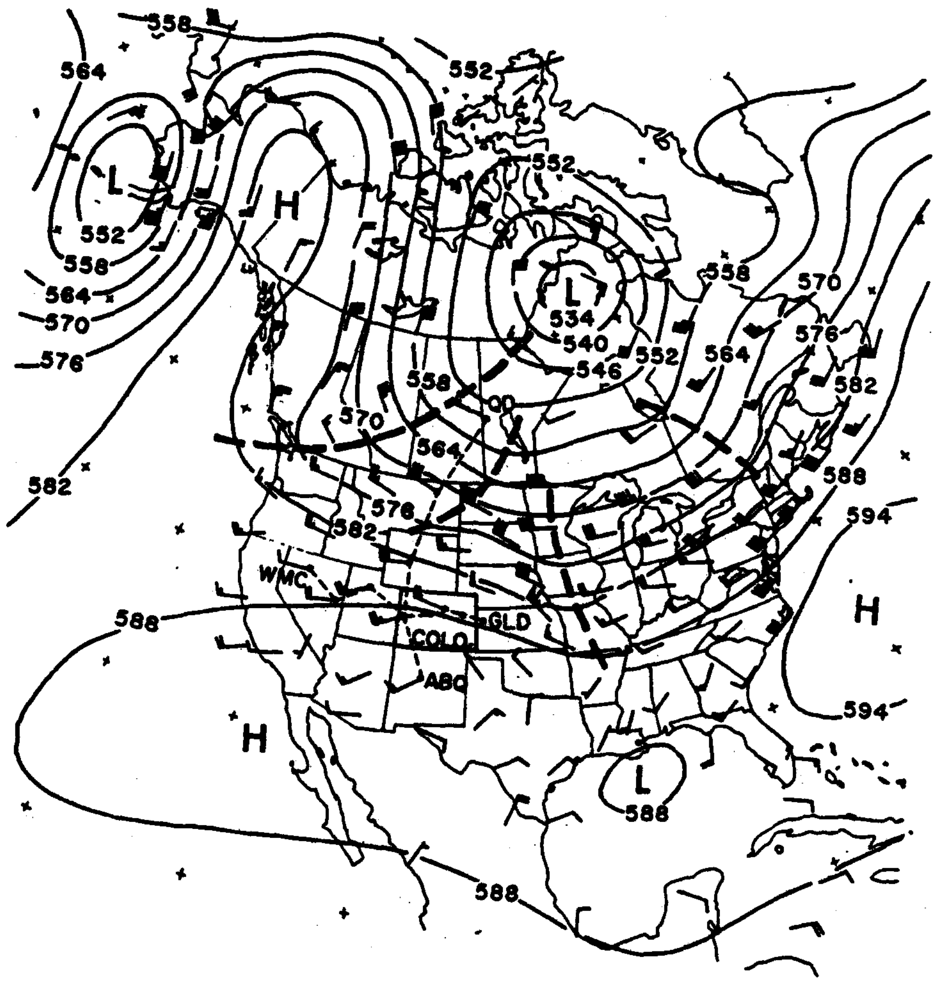
(b) Synoptic/Meso-α Scale Case Studies

The first two MCCs of this episode, 3-4 August and 4-5 August 1977 have been analyzed in detail. The analysis of the second system includes the formation of initial convection over an elevated mountain plateau, the evolution of this convection with its eastward propagation over the foothills and the continued upscale intensification of the system into a mature MCC over the High Plains. Figure 4 shows a satellite sequence of this evolution which is typical of many western MCCs that have their convective roots in the mountains. The 500 mb chart for 1200 GMT, 4 August (Fig. 5) reveals no short wave in the anticyclonic flow over Utah and Colorado that could have triggered the convection. However, the midlevel moisture provided by this westerly flow played a major role in storm development. There is a striking analogy in the scales of interaction for the meso-β scale convection over South Park (involving a local mountain-valley circulation) and the meso-α scale convective system over the High Plains (involving a plateau-plains circulation).

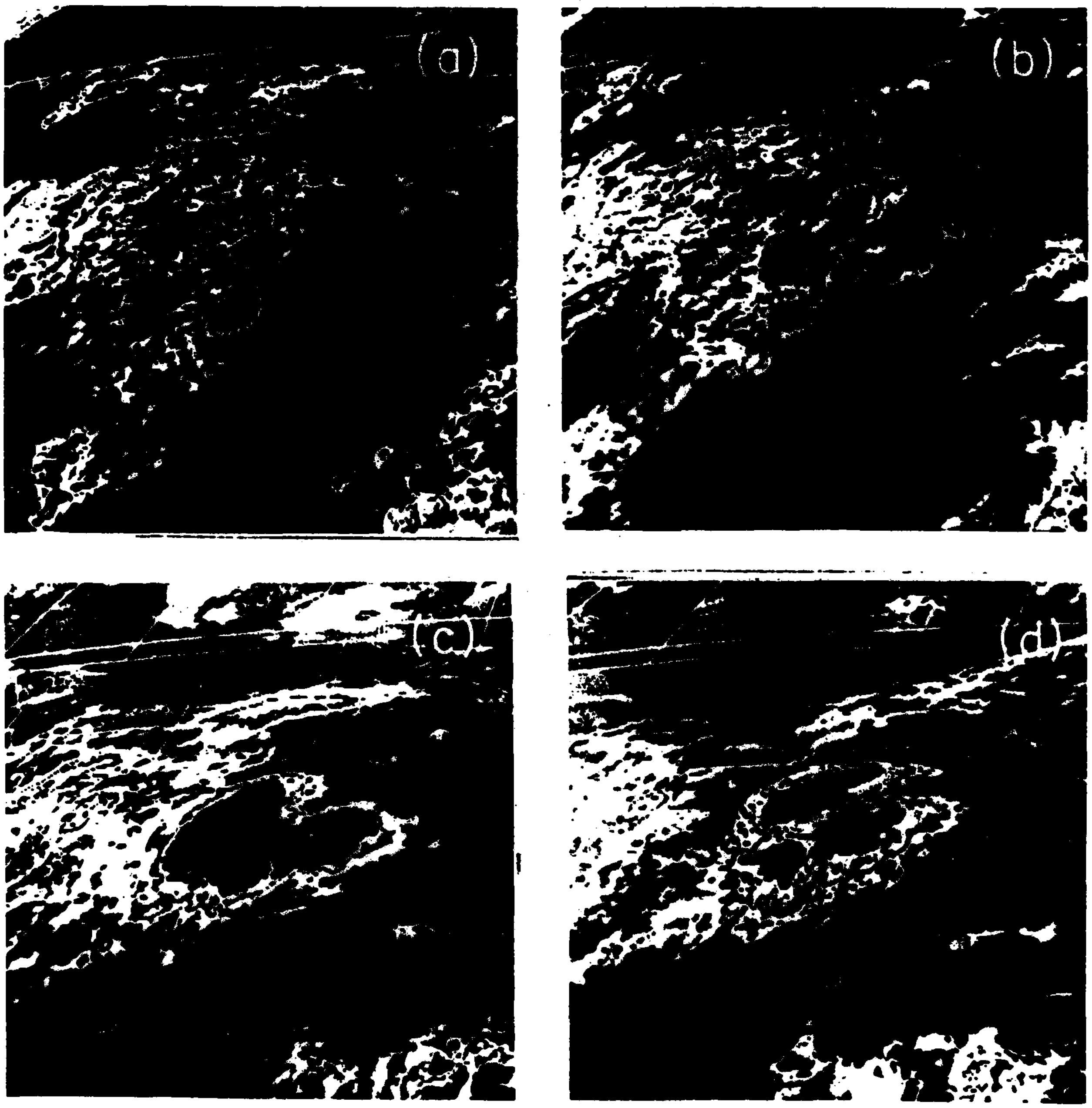
The mature structure of the two systems in their weakening stages were analyzed with 1200 GMT synoptic data. Figure 6 shows a satellite sequence for the evolution of the second system up to this stage. Significant features of the mature system include (1) a warm-core, divergent, anticyclonic perturbation in the mid to upper troposphere (Fig.



4. Enhanced IR images, centered near eastern Colorado, for 4 August 1977. MDT times (a) 1514, (b) 1614, (c) 1715, (d) 1814, (e) 1932, (f) 2100, and (g) 2200 (Cotton et al., 1982).



5. 500 mb height analysis (dm) for 1200 GMT, 4 August 1977. Heavy-dashed lines denote short-wave troughs. Wind pennnants, full barbs and half barbs denote 25, 5, and 2.5 m/s, respectively (Cotton et al., 1982).

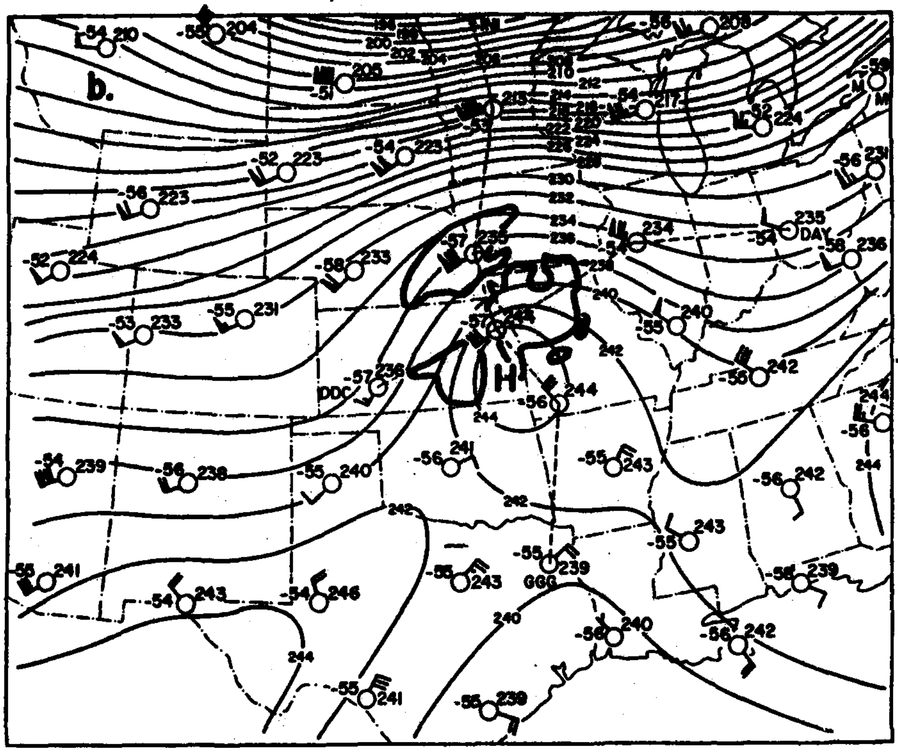


6. Enhanced IR satellite images of central U.S. showing evolution of the second MCC of the episode on 5 August 1977 at (a) 0014 GMT, (b) 0400 GMT, (c) 0900 GMT, and (d) 1200 GMT (Wetzel et al., 1982).

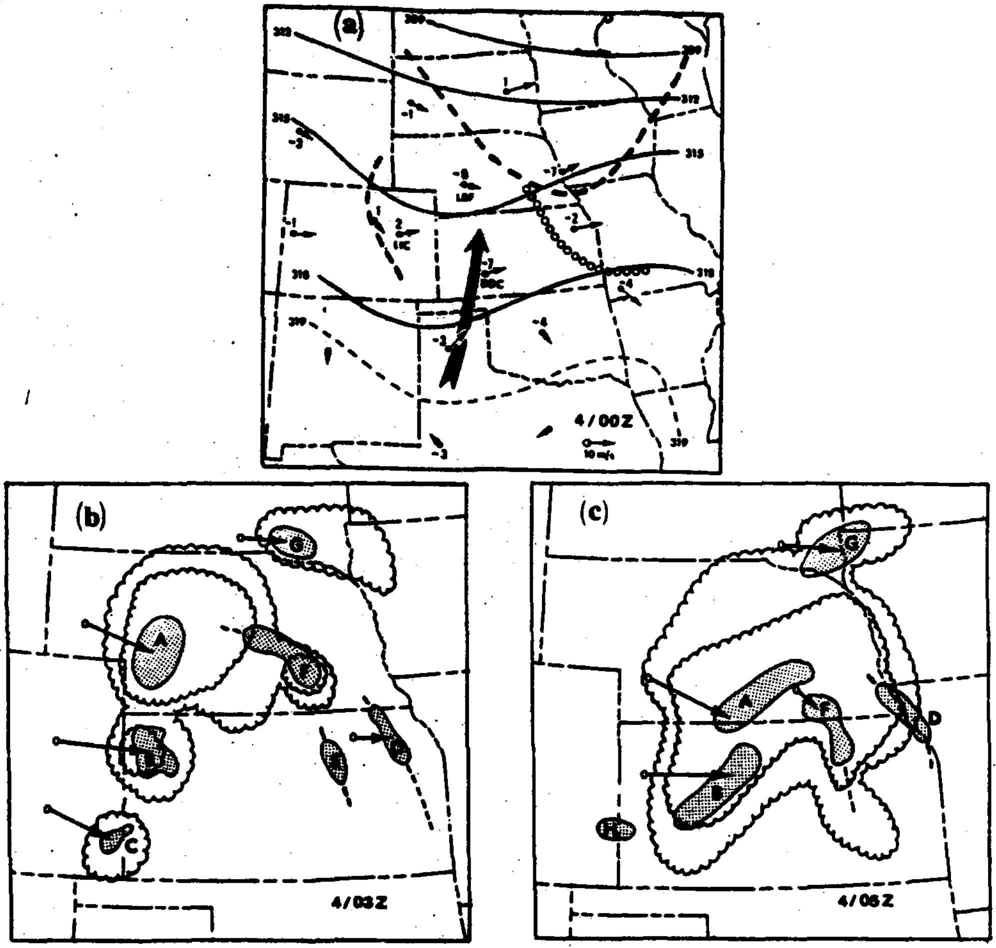
7); (2) divergence profiles averaged over the storm that resemble those for tropical cloud clusters (deep low- to midlevel convergence, strong, shallow upper-level divergence); (3) vertical velocities comparable to baroclinic winter cyclones, but lacking significant baroclinic processes; and (4) a low-level jet supplying moisture to the systems.

c. Meso-β Scale Evolution of MCCs.

The satellite sequence in Figs. 4 and 6 depict the typical upscale development wherein initial convection leads to meso-β scale clusters and eventually to the meso-α scale MCC. Radar, satellite, and hourly precipitation data were analyzed for all of the MCCs in this episode to study their subscale characteristics. Figures 8 and 9 illustrate the meso-β scale radar echo evolution associated with the first two systems. Characteristic subscale features of MCC evolution include: (1) precursory multiple meso-β scale convective clusters; (2) the formation of these clusters along identifiable meso-α scale features (e.g. orogenic lines at the foot of the Rockies, stationary fronts), the confluence and merger of meso-β scale clusters with rapid development into a meso-α scale system, this occurring at the intersection of the meso-α scale discontinuities along which the meso-β scale clusters originate; (3) meso-β scale convective entities (lines and clusters) embedded within the mature system with the instantaneous precipitation pattern being confined to a much smaller area than either meso-α scale cloud shield or the integrated storm rainfall might imply; (4) the diffluence of these meso-β scale entities as the MCC decays; and (5) the potential for severe weather maximizing early in the MCC life cycle, when the meso-β scale clusters are most vigorous.



7. 200 mb height analysis for 1200 GMT 5 August 1977 with the area of IR satellite temperature colder than -53°C shaded and outlined by a heavy solid line. Contours are labelled in dm, (leading "1" omitted). Station data include height, temperature (°C), and winds (full barb = 5 m/s) (Wetzel et al., 1982).



8. Evolution of 4 August 1977 MCC. (a) 0000 GMT 700 mb height analysis (dm) and wind vectors (shown as 3-hour displacement), 850 mb maximum wind axis (broad arrow), surface troughs (heavy dashed lines), axis of residual convection (line of circles), and lifted index (plotted). (b) IR satellite and radar composite chart for 0300 GMT. Shaded regions denote significant meso-β scale convective lines or clusters, with the solid vectors giving the displacement of their most intense centers over the previous three hours. The heavy-dashed segments are axes of weaker convection along which the more intense meso-β scale features are embedded. The outer and inner scalloped lines are the IR isotherms of -40 and -62°C, respectively. (c) Same as (b), except for 0500 GMT. (d) Same as (b), except for 0700 GMT. (e) Same as (b), except for 1000 GMT. The dotted vectors are moist layers to 500 mb wind shear at the selected stations (denoted by large dots) at 1200 GMT (magnitude displayed as 3-hour displacement) (McAnelly and Cotton, 1981).

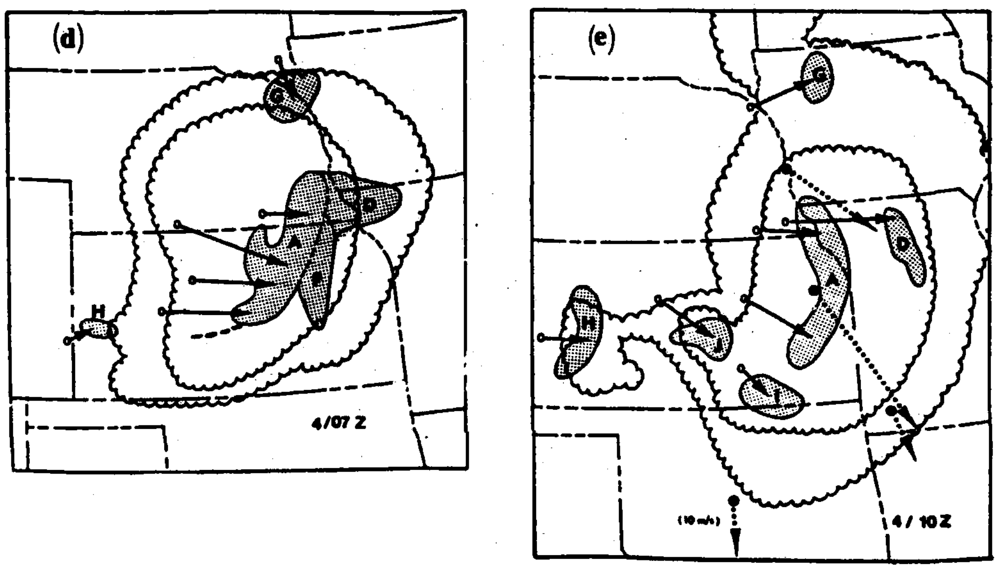
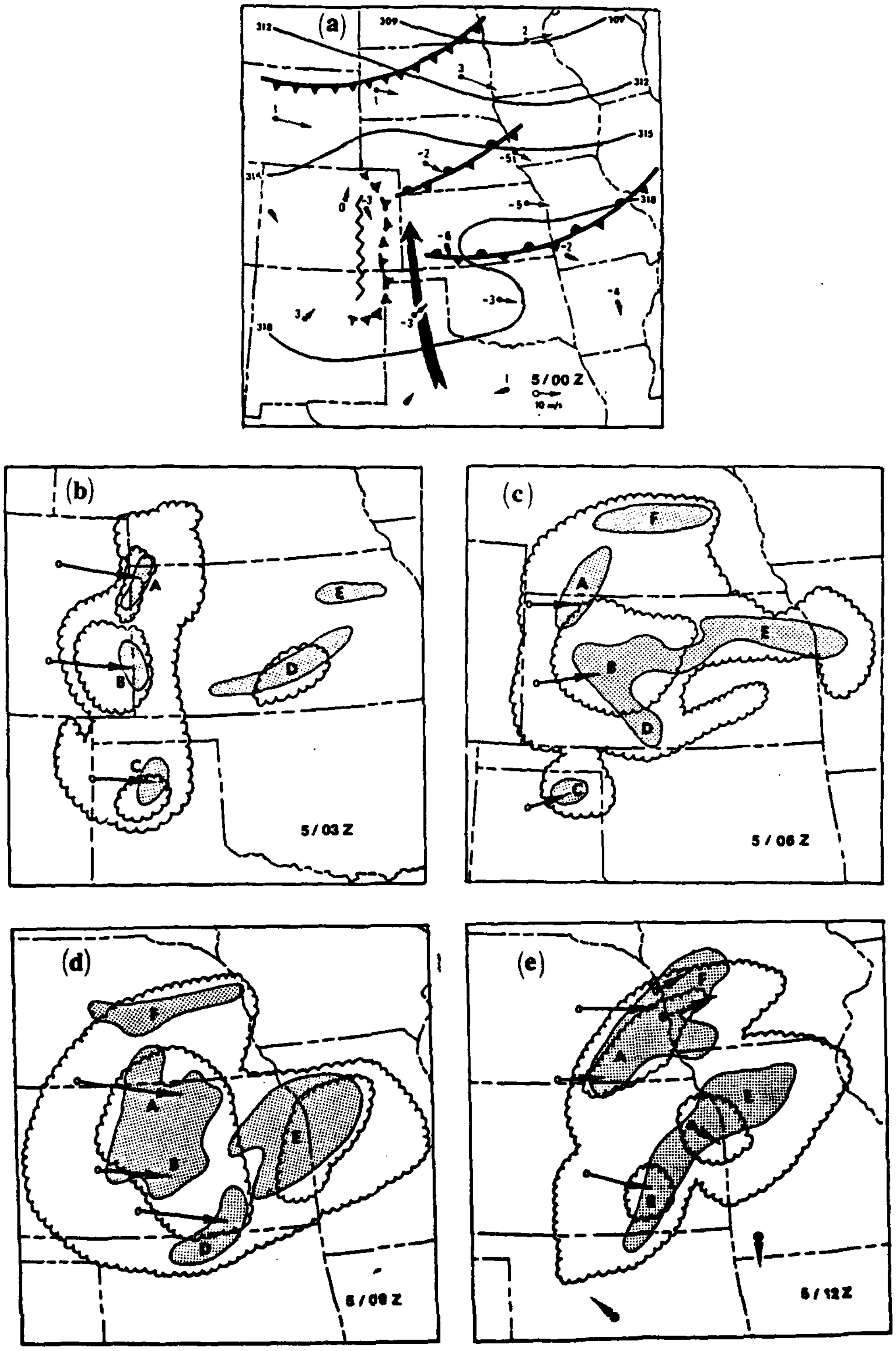


Fig. 8 (Continued)

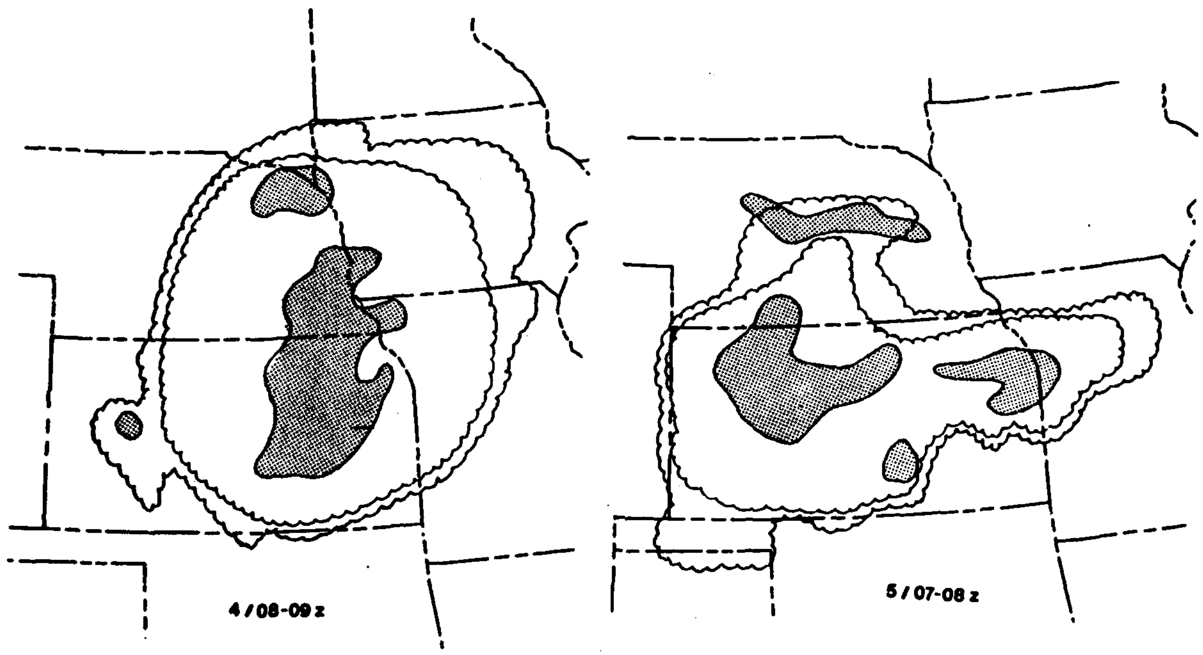


9. Same as Figs. 8a-e, respectively, except for 5 August 1977 at (a) 0000 GMT, (b) 0300 GMT, (c) 0600 GMT, (d) 0900 GMT, and (e) 1200 GMT (McAnelly and Cotton, 1981).

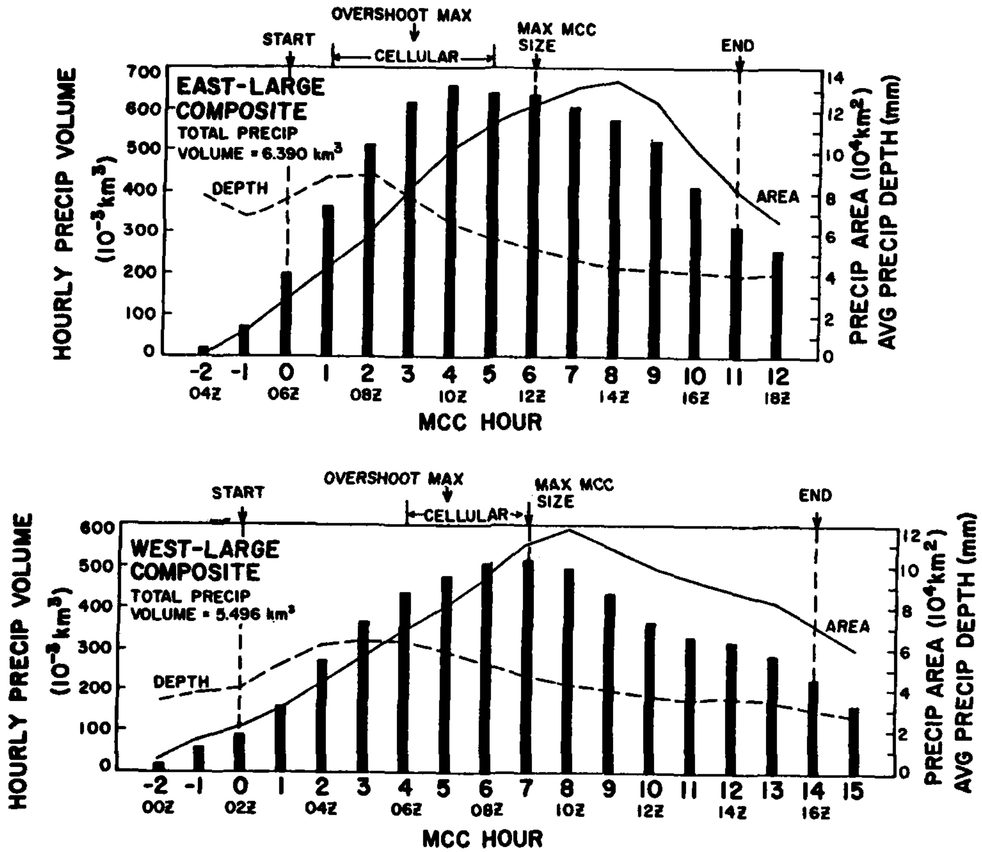
Figure 10 shows examples of one-hour rainfall convergence within MCCs with these meso-β scale areas corresponding to the radar entities depicted in Figs. 8 and 9. Such meso-β scale rain areas exhibited spatial and temporal coherence over several hours, varying in their characteristics from propagating squall lines (oriented perpendicular to the low- to midlevel wind shear), to stationary lines in the less sheared situations, to nonlinear clusters. The hourly precipitation data were analyzed and composited for several MCCs to determine the area of precipitation, average depth of hourly rainfall, and the total storm rain volume as a function of time in the MCC life cycle. Figure 11 shows these analyses for large eastern and western MCCs. While the area of active precipitation increases beyond the time of maximum MCC size, the average intensity of rainfall peaks early in the life cycle when most severe weather events also occur. The resultant hourly rain volume bars in Fig. 11 peak an hour or two before the maximum cloud shield area. The decrease with time beyond this maximum is more gradual than the earlier increase and significant rainfall continues after MCC decay.

2.5. Analysis of Convection Using Composited Satellite Imagery.

In studying the role of elevated terrain in the initiation and development of MCC systems it may be useful to identify those portions of the Rocky Mountain and Tibetan Plateau areas where the initial phases of convection tend to occur most frequently. Sequences of "averaged" composite cloud images for different times of day should reveal both the "hot spots" for initial convection as well as the dominant modes of down wind growth and development. To do this we are compositing digital satellite imagery using a technique developed recently at CSU (Klitch, 1982).



10. Examples of IR cloud shield coverage (isotherms of -40 and -62°C) and contiguous one-hour precipitation reports (shaded region) for two MCCs.



11. Composite hourly rainfall characteristics for large eastern MCCs (top) and large western MCCs (bottom), for three similar MCCs of each type from the 3-10 August 1977 episode. Compositing was based on times of IR satellite features (displayed along the top). Solid line gives the summed areas with rainfall (each hour) associated with the MCC. Dashed line gives the average hourly rainfall amount within the area. The hourly precipitation volumes (bars) are the product of the depth and area.

The image averaging procedure is illustrated in Fig. 12. Typical visible and infrared images of well-developed convection over the eastern slopes of the Rocky Mountains (at 2315 GMT) are shown in Figs. 12a and b. The visible image is used as a guide to locate cold, nonconvective clouds such as cirrus streaks. Further processing, using the CSU Interactive Research Imaging System (IRIS), yields a three-shaded "gray mask" image (Fig. 12c). This procedure allows objective separation of deep cumulus convection (brightest area) from the no-cloud areas (black) and gray areas of low stratus or high thin cirrus clouds. Compositing a month of deep convective images yielded Figs. 12d and e, 1715 and 2115 gmt, respectively, for July 1982. The composite image in Fig. 12c shows that the early stages of daily convection over Colorado, northern New Mexico and eastern Wyoming are heavily concentrated over the highest mountain ranges in the region. By stratifying these sequential composites of diurnal convection by month and for several dominant synoptic regimes, we can further determine where convection begins and how it propogates under a variety of conditions.

The data used for these studies are routinely collected by the GOES-West satellite and read out and archived by the CSU Direct Satellite Earth Station. Because equivalent digital data for Asia are very limited we are also examining the feasibility of developing similar composite images from printed (microfilm) imagery.

2.6 Possible Tropical Connections of MCC Development Over Colorado.

We have begun recently to study satellite images in the infrared spectral region over the tropical and subtropical Atlantic and the Americas. Results of this study, so far, can be considered only as

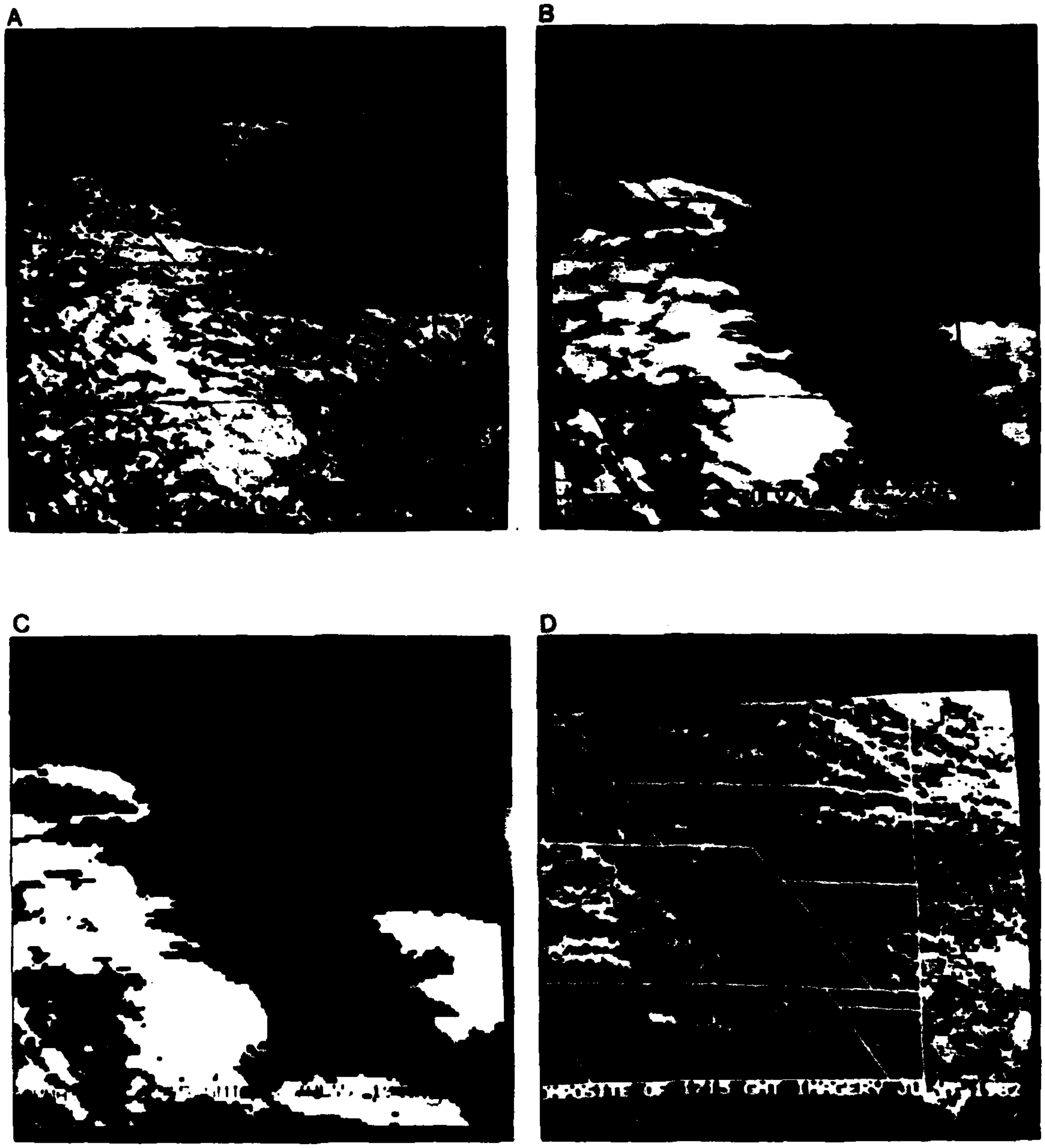


Fig. 12 Image compositing to obtain the "average" diurnal cycle of cumulus convection for July 1982 over the eastern slopes of the Rocky Mountains. (a and b) Typical visible and infrared images at 2315 Z, 28 July 1982. (c) Gray mask image for 2315 Z, 28 July 1982. (d and e) Composite of all July 1982 cumulus convection for 1715 and 2115 Z, respectively.

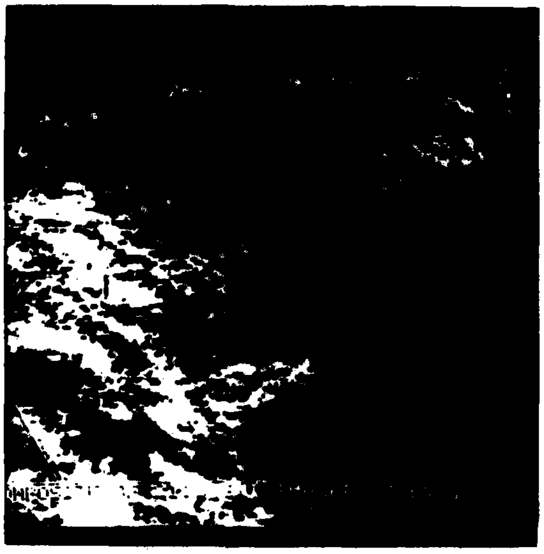


Fig. 12 (Continued)

preliminary. There appear to be two rather different large-scale cloud patterns in the northern hemisphere during summer: Pattern A is characterized by an ITCZ over the northern part of South America and the southern Caribbean, which is studded with extensive mesoscale convective complexes (MCC). Over Central America this cloud pattern splits into two branches: One turns northward over the Central American land masses, follows the Sierra Madre and reaches over the southwest United States as far as Colorado, giving rise to MCCs along its extent. The other branch continues into the tropical Pacific, outlining the position of the ITCZ there. An example of this pattern is given in Fig. 13.

Pattern B exhibits no continuous bridge of cloudiness and MCCs over Mexico and into the southwestern United States.

Our preliminary data inspection suggests that Pattern A is active during time periods when the U.S. monsoon with moisture flux from the southwest is active over the southwestern United States. Pattern B, on the other hand, seems to dominate during break-monsoon conditions. Tropospheric planetary wave patterns appear to be drastically different during the two cloud-pattern types. Pattern A is formed by a trough off Baja California and a high-pressure system over the Gulf of Mexico, similar to what has been described in connection with Fig. 3. The pressure anomaly distribution appears more or less reversed when Pattern B prevails.

We intend to conduct a number of detailed case studies to substantiate and quantify these pattern differences, and their possible relations to extratropical planetary wave patterns.

Our preliminary investigation of MCCs associated with Pattern A revealed that convective complexes tend to recur repeatedly over the

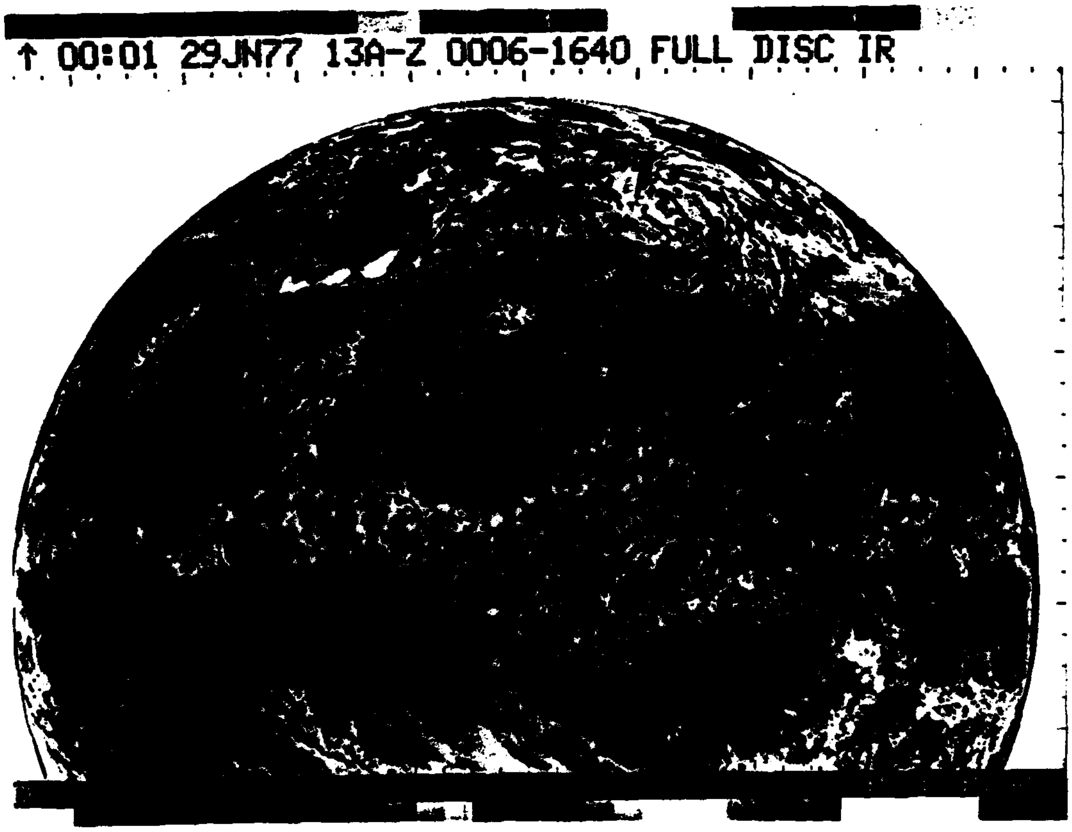


Fig. 13 GOES East full disc enhance IR photograph for 00 GMT, 29 June 1977.

same locations of South and Central America, as also seems to be the case over North America. Such recurrence tendency, in the absence of frontal systems, suggests an important orographic control over MCC formation. Furthermore, we noticed a strong diurnal variation in MCC development with significant phase shifts between land and ocean areas. The diurnal cycle in differential heating between land and sea and between plateaus or mountains and plains has to be held responsible for the observed variation. In addition, however, there appears to be a propagation of impulses along the moisture channel between the southern and northern hemispheres that seems to influence MCC development.

The following procedure was designed to explore the possibility that the convective activity occurring in the branch of cloudiness extending between South and North America is connected to the convective activity over the Amazon region. Seven areas where intense convection repeatedly occurred are shown in Fig. 14. Eight days on which this convective branch over Central America was present were studied. They are June 28, 29, 1977; July 6, 10, 1978; June 29, 30, 1979; and July 8, 9, 1980. For four times on each day (00 GMT, 06 GMT, 12 GMT, 18 GMT) the areal extent within each of the seven regions designated above for which the IR temperature was -52°C or below was estimated. This was done by placing a grid over each of the enhanced IR pictures and estimating the area with dark gray, black, or white (surrounded by black) shading. Then, for each of the seven regions the eight-day mean area for which the IR temperature was -52°C or below was found for each of the four observation times. The mean diurnal curve for six of these regions as well as the diurnal curve for the period June 28, 29, 1977 is given in Fig. 15. On June 28, 1977, at 00 GMT the area in Region 2 with

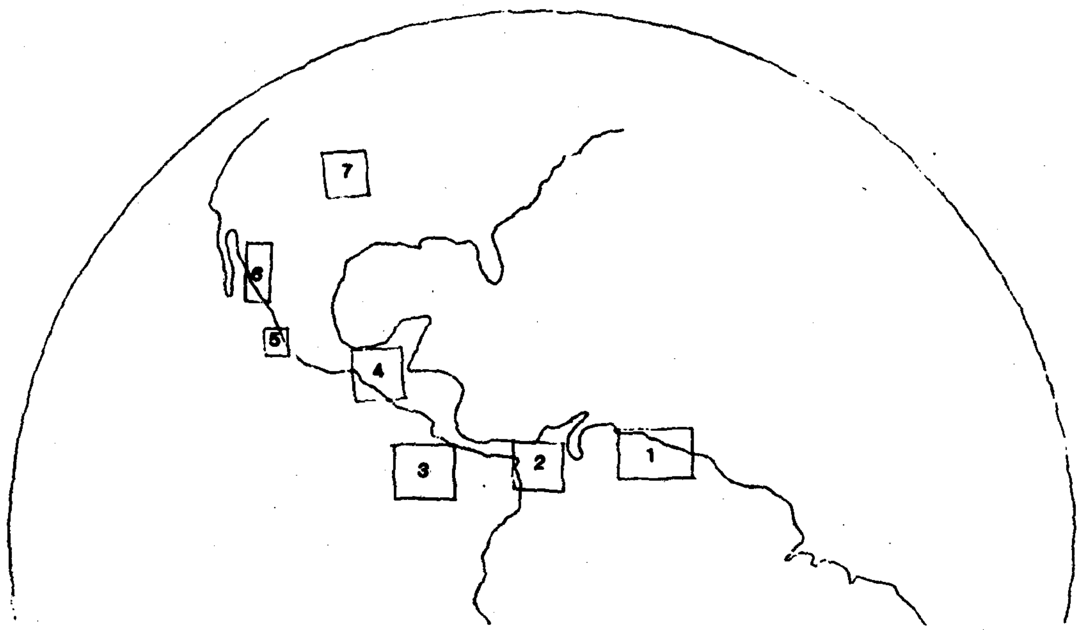


Fig. 14 Regions designated for detailed MCC variability.

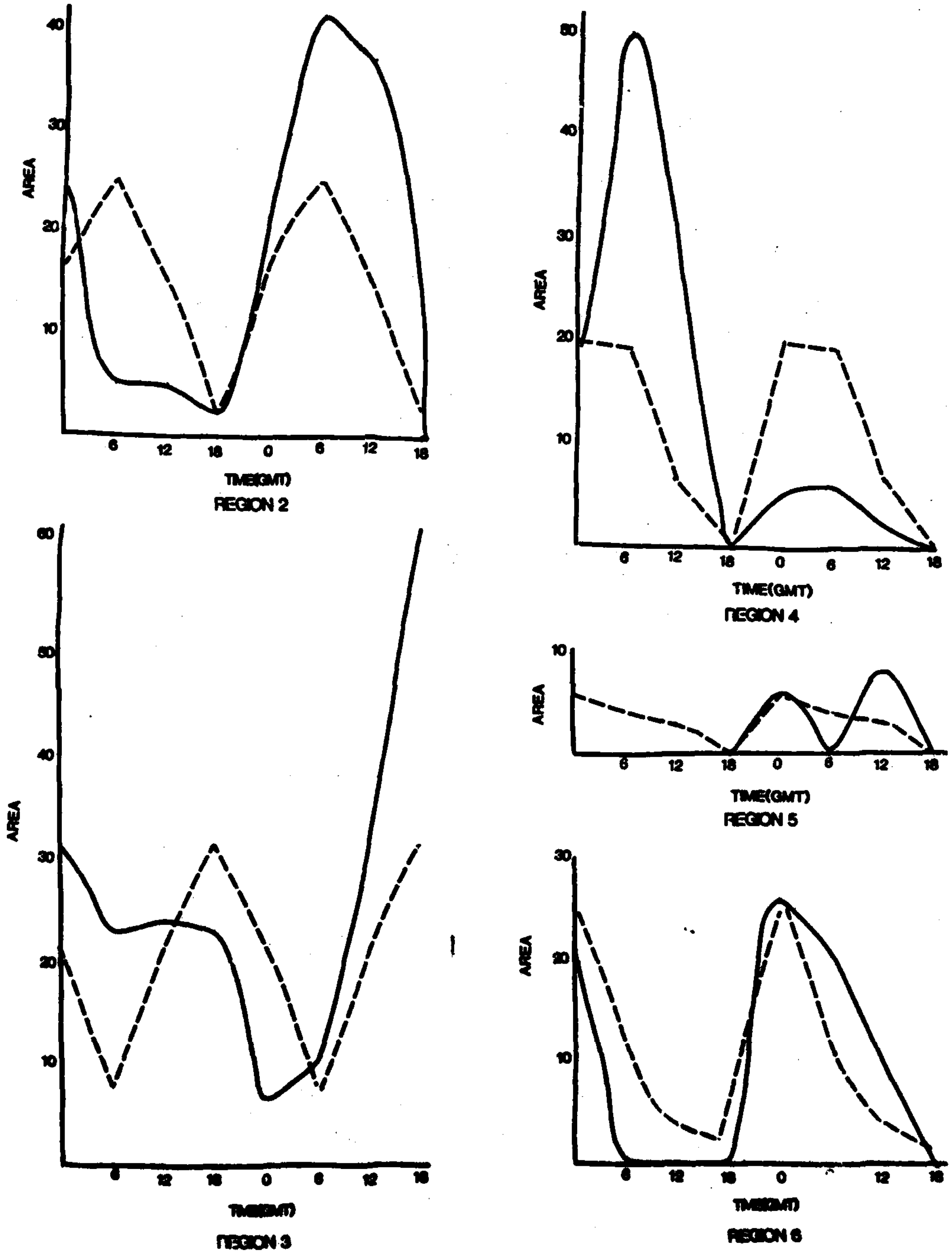


Fig. 15 Mean diurnal variability in each of 7 regions (see Fig. 14) of areas with cloud top temperatures < -52°C (dashed lines) and extent of these areas on June 28, 29, 1977.

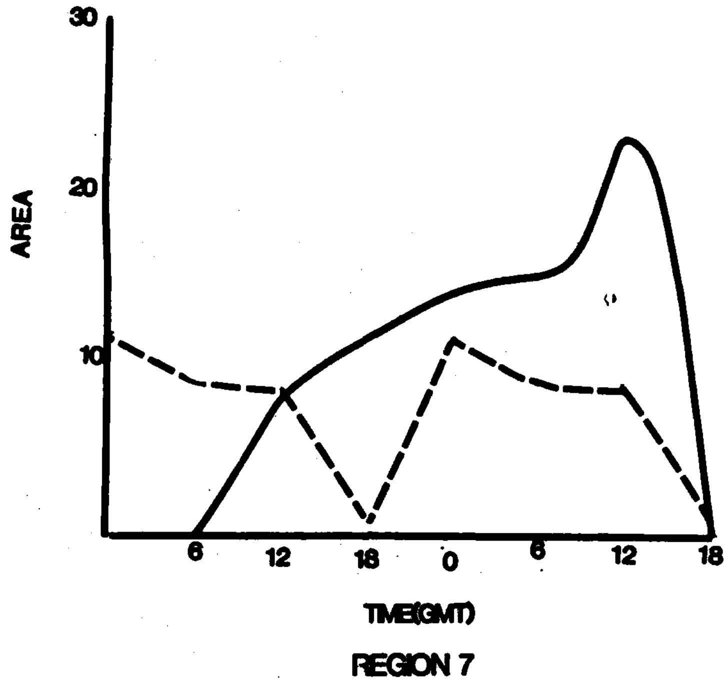


Fig. 15 (Continued)

an IR temperature of -52°C or below was larger than the eight-day mean. This was also true at 06 GMT and 12 GMT on June 29 in Region 2. Region 3 at 00 GMT and 06 GMT, June 28, 1977 and at 18 GMT, June 19, 1977 shows similar anomalies. Region 4 shows even larger anomalies at 06 GMT and 12 GMT, June 28, 1977 and Region 7 at 06 GMT and 12 GMT, June 29, 1977. At 00 GMT on June 29 an area of strong convection was located directly between Regions 5 and 6. Therefore, the diagrams for these two regions exhibit only relatively small anomalies during the satellite observation times. Probably the time resolution of the satellite data is not adequate to reveal a continuous progression of the MCC enhancement.

There seems to be a propagating wave phenomenon moving from Region 2 to Region 7 between 00 GMT, June 28, 1977 and 12Z, June 29, 1977. Such propagating phenomena also appear on the other days studied, but only one case is presented here. The high phase velocity of this phenomenon would suggest a gravity wave, or a series of gravity waves, to be traveling along the moisture channel between South and North America. Gravity waves have been observed to propagate at speeds up to 50 m/s (Eom, 1975). They have also been observed to produce, as well as to be produced by, severe thunderstorms (Uccellini, 1975; Hung et al., 1980). Balachandran (1980) observed such waves to travel distances of 1000 km without much dissipation but it seems that for the distances involved in the case illustrated here there may be a "chain reaction", whereby gravity waves initiate severe thunderstorms which will in turn produce more gravity waves. Such waves will be focussed within a channel within which conditions are conducive for the development of severe convective systems.

2.7. Numerical Modelling Studies.

(a) At the present we have access to three models, one by Anthes and Warner (1978), one by Pielke and Mahrer (1975), and one by Cotton and Tripoli (1978), which allow the study of MCC development. Actual employment of such models will be delayed, however, until the nature of the propagating wave phenomenon discussed in Chapter 2.6 has been substantiated. If, indeed, it were a gravity wave phenomenon, the non-hydrostatic Cotton-Tripoli model will receive preferential attention.

(b) The exchange and transformation of sensible, latent and radiant heat energy over the plateau surfaces is being investigated using a modelling procedure described by Deardorff (1978). This model computes values for soil surface temperatures and heat flux to and from the soil as a function of the turbulent and radiative fluxes at the surface and from an estimate of deep soil temperatures. The computation of the atmospheric fluxes is based on several physical or quasi-emperical relations driven by surface synoptic weather data. The influence of deep soil temperatures is included as an additional term in a simple rate equation used to estimate soil surface temperatures. The influence of soil hydrology is introduced by Deardorff (1978) by extending the same procedure used for the deep soil heat flux (termed the Force Restore Method) to describe the vertical diffusion of deep soil moisture. In the same report Deardorff (1978) also describes the inclusion of a simplified, one-layer parameterization of plant cover. Because of the relative economy and apparent accuracy of this approach, we have adopted it to estimate the short-term variations in the surface energy balance over the plateau areas.

The synoptic data described in Section 2 of this report will be used to compute the surface energy fluxes. Because we are especially interested in the impact of lingering mountain snow cover on the initiation of convection in spring and early summer, we have acquired a climatology of snow cover data (Dewey and Heim, 1981). This data set includes gridded weekly snow cover data (digital tape) plus more detailed (hard copy) weekly analyses of northern hemisphere snow cover for 1966 through 1980.

We are testing and calibrating this model against several sets of soil temperature data. Figure 16 shows soil heat flux values obtained with a very preliminary version of the model (lacking parameterization for vegetation cover) and values computed from soil temperature data at Fort Collins, Colorado. The model reproduces the same general pattern of positive and negative variations but the amplitudes of the modelled values tend to be too large, illustrating the importance of vegetation cover (in this case short grass) in mitigating soil heat flux.

Modelled and measured soil surface temperatures are shown for comparison in Fig. 17. The data used for these calculations are for Lhasa, Tibet. The observed surface temperatures were obtained by laying a thermometer on the ground (Y.-X. Gao, Lanzhou Institute of Plateau Physics, private communication). The model results are again quite preliminary and were obtained without benefit of reliable initial data for either deep soil temperatures or moisture and also without cloud cover information. (As noted in Section 2 we now have a good set of Chinese soil temperature data and cloud cover information which have been obtained from NCAR and from Lanzhou.)

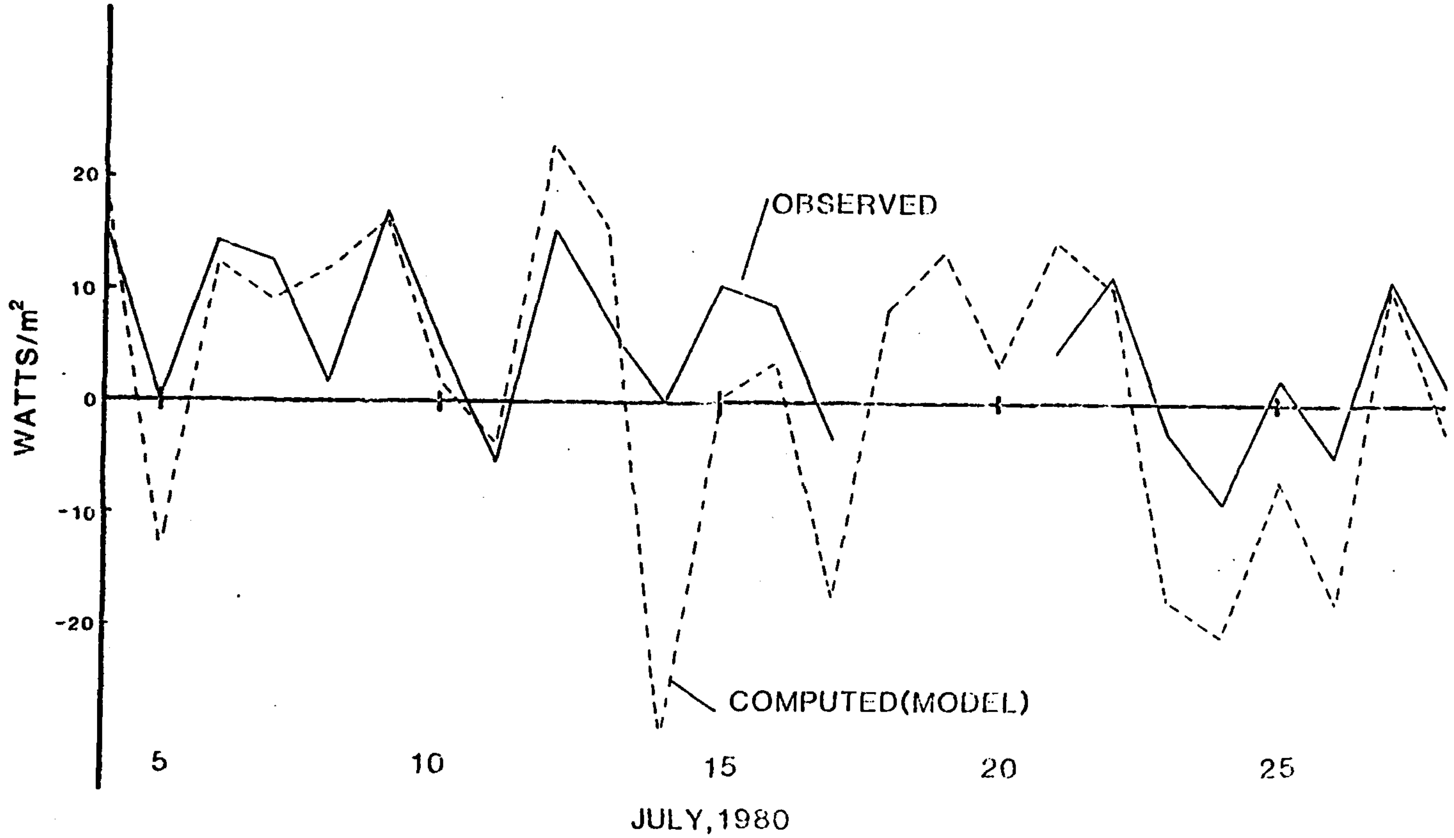


Fig. 16 Time series of comparative (observed and modelled) daily soil heat flux for Fort Collins, Colorado, during July 1980. The observed values were computed from the diurnal changes in soil temperatures (observed at 7 a.m.) measured at 11 levels to 3 meters below the surface.

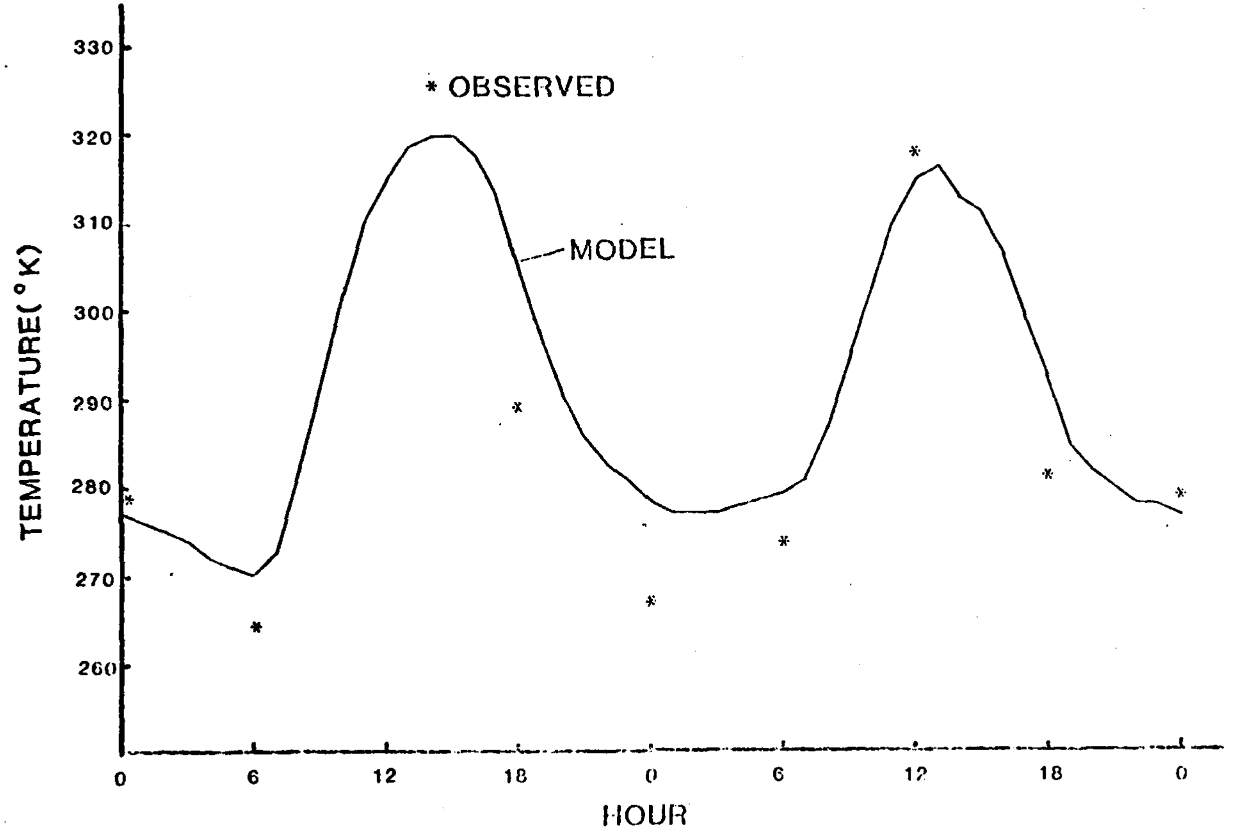


Fig. 17 Modelled (hourly) and observed (every 6 hours) soil surface temperatures at Lhasa, Tibet, for April 9 and 10, 1979. The temperature observations were obtained by laying a thermometer on the ground surface. The modelled temperature values were based on assumptions of no vegetation and rather dry, sandy soil.

(c) For analyzing large-scale horizontal transport of water vapor, we have an isentropic trajectory model (Trenback, 1980) for use with the 1977 NMC grid point data set and other data. The application of this model is primarily for the identification of moisture sources important for convection in the lee of the Rocky Mountains, with the goal of establishing the role (or existence) of a North American southwest monsoon. The model is initialized with wind and stream function data at hour 0 and computes one-hour trajectories, updating the stream function field at each hour. We have begun the analysis of moisture trajectories for the transition period leading into the MCC episode of 3-10 August 1977.

3. Field Instrumentation.

On 30 September, 1982, we received a supplemental allocation of our research grant which allows us to acquire instruments to measure soil and atmospheric heat, moisture and radiation fluxes near the earth's surface. These instruments are intended to be deployed in mountainous terrain where surface energy budgets and their influence on atmospheric circulation systems are still open to conjecture.

During the past few weeks we have contacted, and solicited bids from, those vendors which have supplied us with similar equipment which is now deployed in the Empty Quarter of Saudi Arabia for the purpose of measuring surface energy fluxes in a desert environment. These bids are presently being received.

We also have started negotiations with officials from the PRC (Prof. Gao Youxi, Director of the Institute of Plateau Atmospheric Physics, Academia Sinica, Lanzhou, personal negotiations; and Mr. Zou Jingmeng, Director General, Central Meteorological Bureau, Beijing,

negotiation by correspondence and through Dr. Eugene W. Bierly, NSF) to allow deployment of some of these instruments in the plateau regions of the PRC under the condition of unrestricted access to the data by us. No results of these negotiations are available as yet.

Acknowledgments

Some of the MCC analyses were partially supported by NSF Grants ATM 76-83361 and ATM 79-08927, Bureau of Reclamation Grant 7-07-B0006, and NASA Grant NSG-0511.

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